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Extent and Composition of the Incrustation on some Filter Sands

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EXTENT AND COMPOSITION OF THE INCRUSTATION ON SOME FILTER SANDS

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BY

CHARLES ERNEST MILLAR

B. S. University of Illinois, 1909

THESIS

Submitted in Partial Fulfillment of the Requirements for the

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CHARLES ERNEST MILLAR

ENTITLED EXTENT AND COMPOSITION OF THE INCRUSTATION OF SOME FILTER SANDS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE OF CHEMISTRY

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Committee
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EXTENT AND COMPOSITION OF THE INCRUSTATION ON SOME FILTER SANDS.

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For several years complaints of increase in size of sand grains in filter beds have been made by operators of filter plants The trouble occurs at plants where lime is used, and it may be said that treatment with lime leads to incrustation of the sand unless some means are used to prevent it. At times the incrustation is so great that the sand must be renewed, and cases have been reported where that near the bottom has become caked into a solid mass.

The Municipal Journal and Engineer. -- May - 1908.
Water and Sewage Purification in Ohio. Report State Board of Health, 1908 -- pp. 164-165, 181-182, 195, 313-314, 341, 353.

From the above we have been led to make an investigation to ascertain the condition of sands in the Illinois filters. We wrote to several filter plant operators asking for samples of sand which had been in use for some time. Five samples were received. We are indebted to Mr. C. H. Cobb, of Kankakee, Mr. H. M. Ely of Danville, Mr. W. H. Gelston of Quincy, and Mr. W. Olson of Moline for the samples and data concerning them.

The Quincy sand was Red Wing Filter Sand No. 1 with an effec-

tive size of 0.38 m.m. and a uniformity coefficient of 2.1 m.m. when placed in the filters. It is impossible to say how long this sand has been in use, since, two years ago the sand from all the filters was removed and screened. That passing a twenty mesh sieve was returned to the beds and the remainder thrown away. During the last two years the water has been treated with lime and iron sulphate, 2.05 grains per gallon of iron sulphate and 2.84 grains of lime being used.

Unfortunately little data is available regarding the Kankakee sand. No record of the original effective size or uniformity coefficient could be found. The sand has been in use for nine years. Alum was used in treating the water for eight years when the treatment was changed to 1 grain per gallon of iron sulphate and 2 grains per gallon of lime.

The Danville No. 8 sample was Red Wing filter sand with originally an effective size of 0.31 M.M. and a uniformity coefficient of 1.8 m.m. The sand has been in use for seven years and until Jan. 1, 1910 lime and iron sulphate have been used in treating the water. The amount of iron sulphate used varied from .58 to 1.50 grains per gallon during periods of low turbidity and from 2.50 to 4.00 grains per gallon during season of high turbidity. Lime was added in amounts varing from .27 to .7 grains per gallon when the turbidity of the water was low and from .8 to 2.5 grains per gallon when the turbidity was high, after the first year, and to within a year and a half of the time the sample was

taken even greater amounts of lime were used. Since Jan. 1,1910 hypochlorite of lime has been used a portion of the time.

The sand in filter No. 6 of the Danville water works was Red Wing sand with an effective size originally of .31 m.m. and a uniformity coefficient of 1.8 m.m.

The sand has been in use for 5 years. During the last year and a half of this time the treatment has been the same as in the case of filter No. 8. That is - .27 to .7 grains per gallon of lime and .58 to 1.50 grains of iron sulphate during seasons of low turbidity and .8 to 2.5 grains per gallon of lime with 2.5 to 4.0 grains of iron sulphate, when the turbidity was high. Previous to this time larger proportions of lime were used. Since Jan. 1, 1910 hypochlorite of lime has been used part of the time

The Moline sand has been in use for five years, during which time the water was treated with 1 grain per gallon of iron sulphate and 3 grains of lime with the exception of nine months when alum was substituted. No data concerning the original sand was available.

The experimental work consisted in the determination of the amount of incrustation, not only on the sand as a whole but on the grains of various sizes. The composition of the incrustation and the relative size of the grains was also determined, and means of preventing incrustation studied.

The amount of incrustation on the sand grains was determined by removing it by means of acid from a known weight of the sand. The residual sand was then thoroughly washed and weighed. The results are shown in the following table:-

Name of Sand	Danville No. 8	Danville No. 6	Kankakee	Quincy	Moline
Weight of Sand Taken	343.0	351.3	383.0	325.0	330
Weight of Residual Sand	231.8	238.2	330.4	48.7	94.4
Weight of Residue Removed	111.2	113.1	52.6	276.3	235.6
Per cent of Incrustation	32.4	32.2	13.7	85.	71.4
Percent Increase by Incrustation.	47.9	47.7	15.9	633	249.

We hardly realize what an enormous growth these figures represent until we consider the percentage increase. An incrustation of 85% represents an increase of 633%. This means that an equivalent amount of sand has been carried into the sewers, as the volume of sand in the filters does not increase. An incrustation of 71.4% then would represent an increase, and therefore the loss of an equivalent amount of sand, of 249%.

This increase in volume is caused by the increase in size of the sand grains and so changes naturally the effective size and coefficient of uniformity of the sand and consequently the effectiveness of the filter. It might be said that the effective size of a sand is the diameter of the meshes of a sieve that allows ten percent of the sand to pass through it. In other words the diameter of the largest grains that go to make up the finest

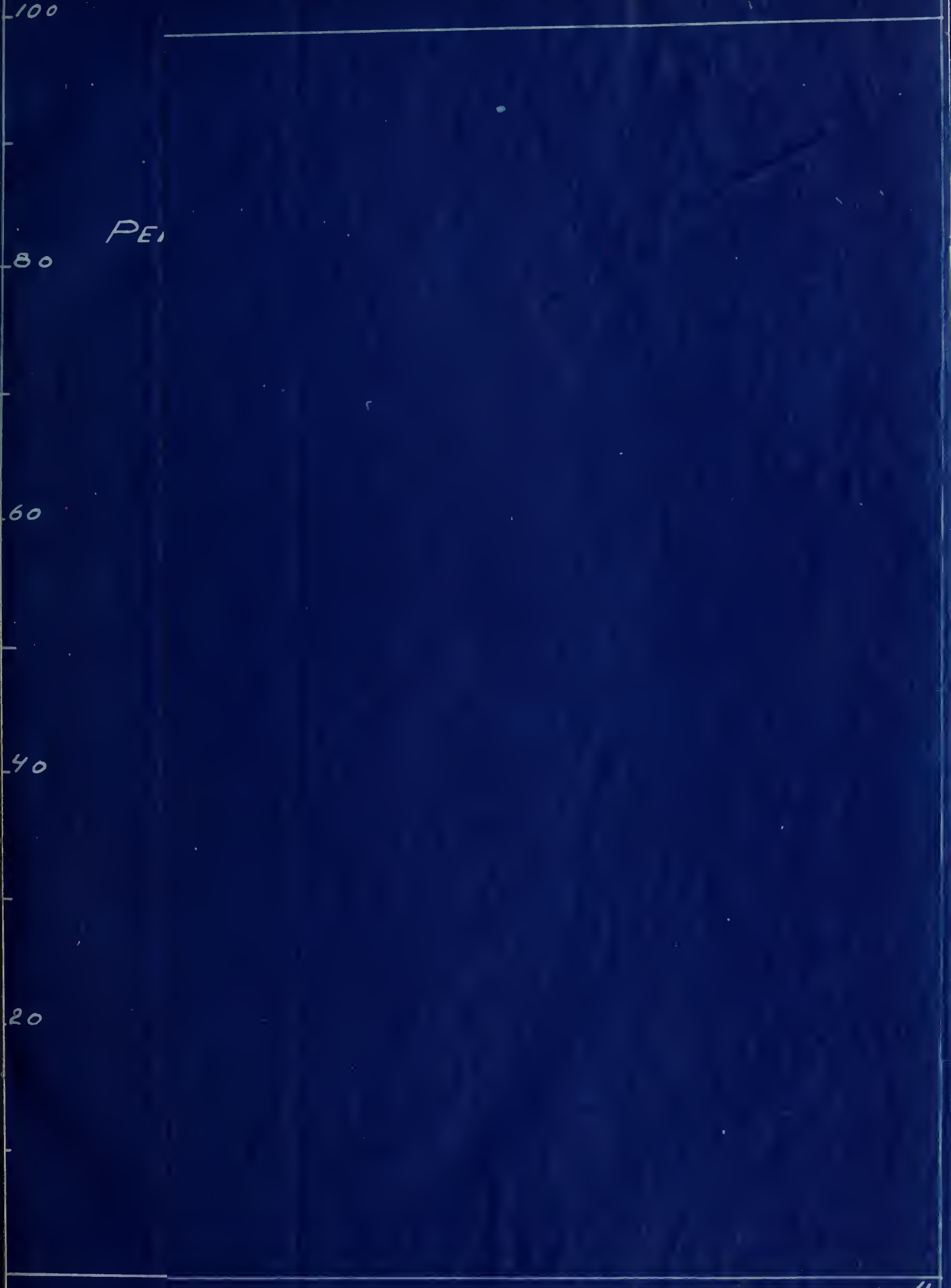
tenth of the sand. The coefficient of uniformity is found by dividing the size of separation of a sieve that allows sixty per cent of the sand to pass through by effective size, or size of separation of a sieve that allows ten per cent of the sand to pass it. The effective size then tells us the size of the finer particles of sand, and so gives us an idea of how thorough the filtration will be. Ordinarily a sand having an effective size of more than .30 millimeters should not be used. The coefficient of uniformity tells us the average size of the sand grains, which is a very important factor in the construction of efficient filters.

A sieve analysis was made of the incrusted sands. From this data the effective size and coefficient of uniformity were calculated and the results compared with the data concerning the original sand when such data was available. The results appear in the following tables and curves. (See Table and Curves).

It is interesting to note the effect of incrustation on the effective size and coefficient of uniformity of the sands. When ever the data concerning the original sand is available it will be noted that the coefficient of uniformity is much decreased while the effective size is greatly increased. In the case of the Danville sands the effective size is increased by a half and for the Quincy sample it is doubled. Such marked changes show how the sizes of the grains have increased and therefore of course the interstices must be much greater. That in turn means that larger particles of foreign matter in the water are allowed

Sieve Analysis of Sand.

Incrusted Sand.						Original Sand.	
Name of Sand.	Size of Sieve.	Size of Separation of Sieve Milimeters.	Percent of Sand Passing	Coefficient of Uniformity.	Effective size - Milimeters	Coefficient of Uniformity.	Effective Size.
Danville No. 6.	50	0.32	0.06	1.30	0.52	1.80	0.31
	40	0.49	3.01				
	30	0.68	59.60				
	16	1.05	98.40				
	10	1.80	99.90				
	8	2.32	100.00				
Danville No. 8	50	0.32	0.06	1.50	0.55	1.80	0.31
	40	0.49	0.76				
	30	0.68	35.26				
	16	1.05	97.06				
	10	1.80	99.60				
	8	2.32	99.70				
	5	4.42	100.00				
Quincy	50	0.32	0.01	1.67	0.77	2.1	0.38
	40	0.49	0.02				
	30	0.68	0.21				
	16	1.05	47.04				
	10	1.80	99.84				
	8	2.32	100.00				
Kankakee.	50	0.32	0.16	1.68	0.61	Not known	Not known
	40	0.49	1.58				
	30	0.68	14.42				
	16	1.05	62.62				
	10	1.80	98.80				
	8	2.32	99.10				
	5	4.42	100.00				
Moline.	50	0.32	0.15	1.65	0.60	Not known	Not known.
	40	0.49	0.30				
	30	0.68	15.50				
	16	1.05	50.10				
	10	1.80	95.60				
	8	2.32	99.70				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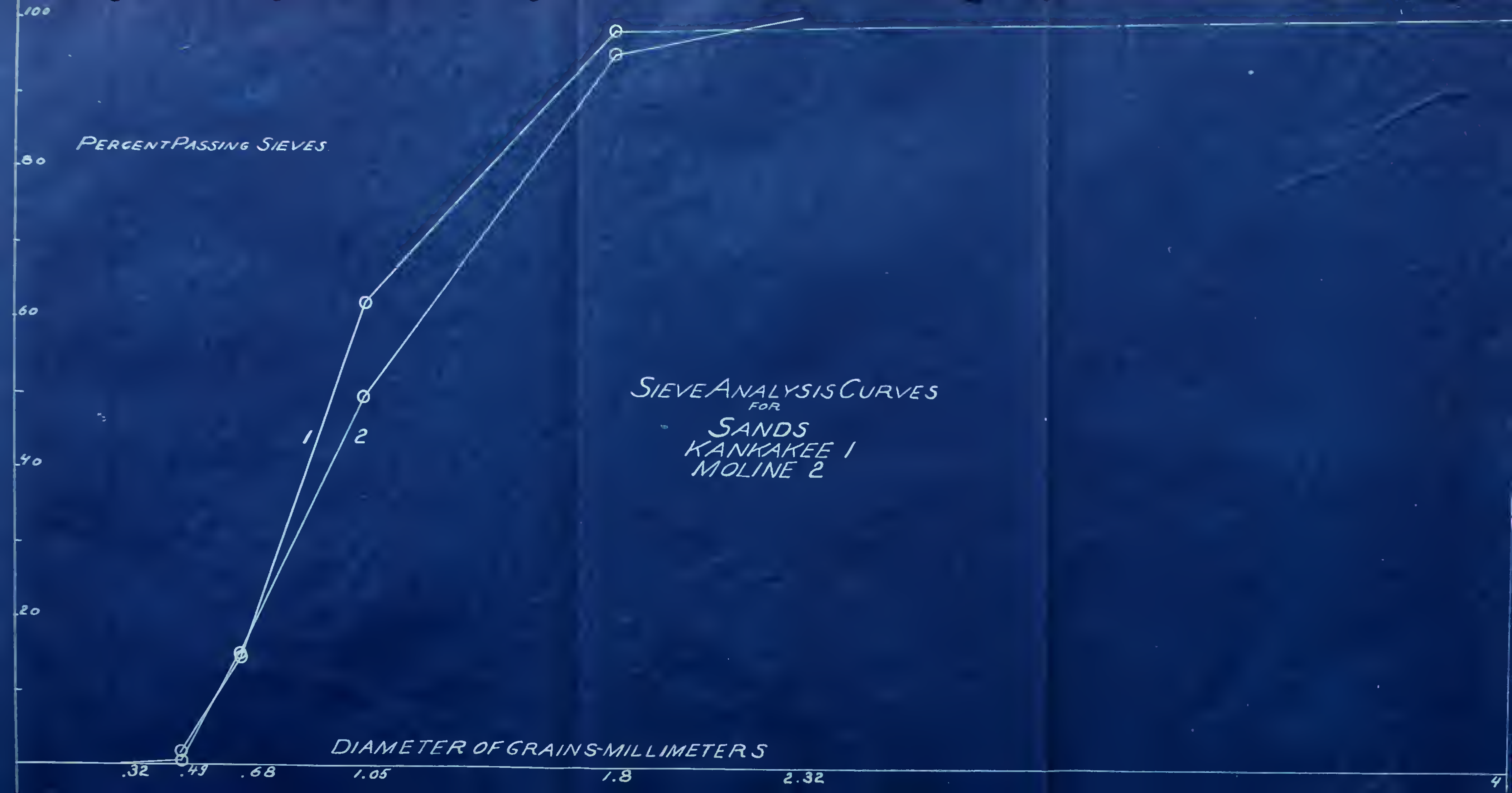
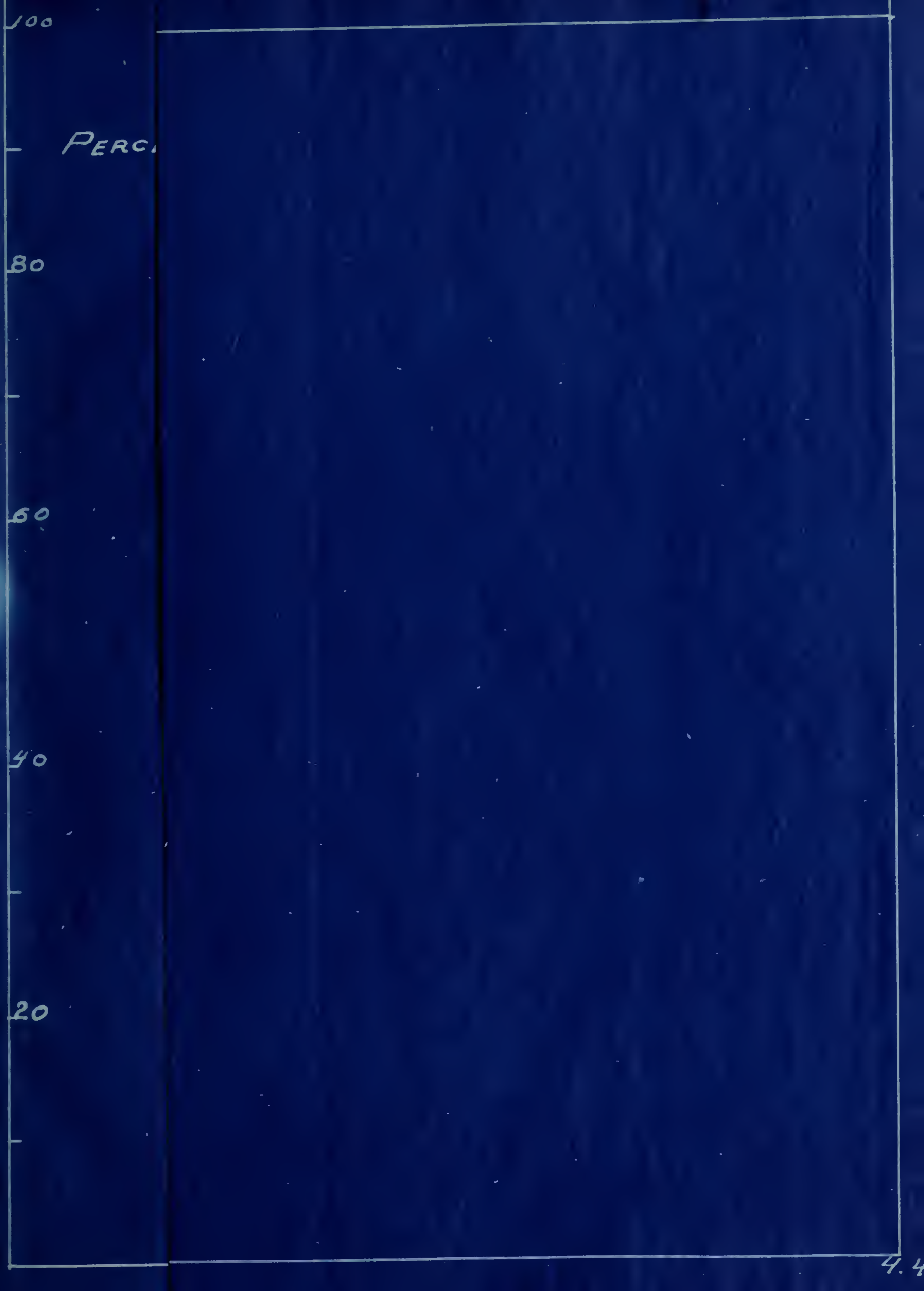


SIEVE ANALYSIS CURVES FOR SANDS KANKAKEE 1 MOLINE 2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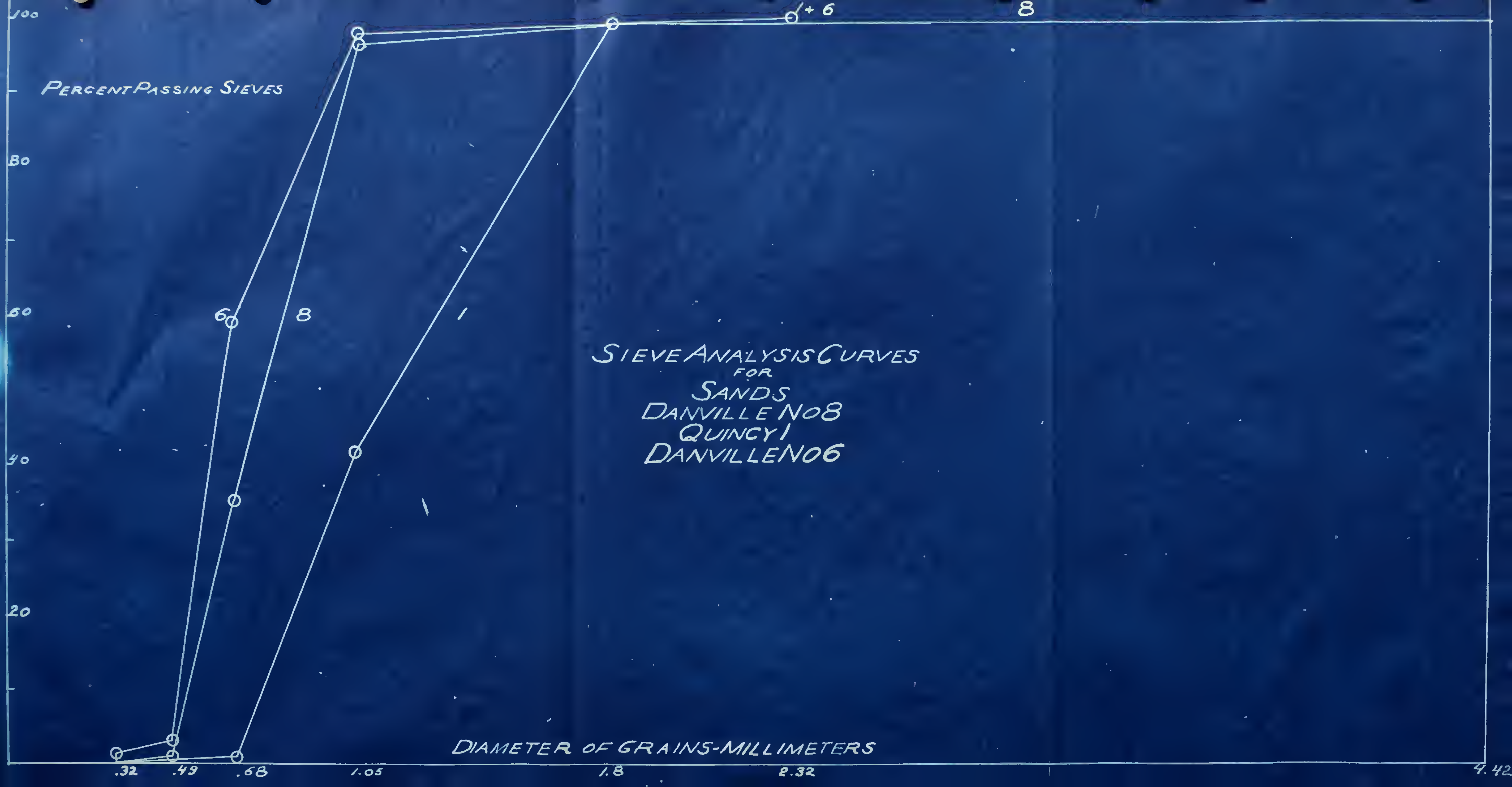


SIEVE ANALYSIS CURVES
FOR
SANDS
DANVILLE NO 8
QUINCY 1
DANVILLE NO 6

to pass through the filter and hence the filtration is not so ~~tho~~ thorough as when the sands were first put in place.

The curves show the change in size of grains in Danville filters No. 6 and 8 to be practically the same, as is to be expected since the water passing through each was the same. The great extent horizontally with but little inclination toward the vertical of the Quincy curve indicates the disappearance of the finer grains and prophesies the great effective size the data shows. The gradual rise as compared to the Danville curves also indicates a larger coefficient of uniformity. The Kankakee and Moline curves while not showing the tendency toward the horizontal shown in the Quincy curve still do not rise so directly as in the case of the curves representing the Danville sands. Hence we would expect an effective size between that of the Danville and Quincy sands together with a rather large coefficient of uniformity.

On the whole a glance at the curves shows that all the filters should be refilled with fresh sand.

Rapid sieve analyses were made on 100 gram samples of the sands using sieves with sizes of separation of approximately 2.0 m.m.; 1.00 m.m.; 0.7 m.m.; 0.5 m.m. The amount of incrustation on the various sizes of sand was then determined.

The larger particles or those having a diameter of 2.0 m.m. or greater, seemed very free from incrustation. There were few particles of this size in the samples and their presence was perhaps more or less accidental. They doubtless came from the lower

strata of the filter beds.

The very fine grains with a diameter of 0.5 mm. or less, were rather heavily coated, the average percentage being 28.8. The heaviest incrustation was found on the medium sized grains, that is those having a diameter of from 0.7 mm. to 1.0 mm. The average incrustation for grains of this size being 37.5%. In one case the incrustation for grains of this size amounted to 83.6% and for particles having a diameter of slightly over 1.0 milimeters - 85.3%. This sand, however, had been removed in 1908 and screened, only that portion passing an 18 mesh sieve and catching on a 24 mesh, being replaced.

The chemical composition of the scale from the several sands was determined as follows: Ten grams were accurately weighed and the incrustation removed by hydrochloric acid. The remaining sand was carefully washed dried and weighed. The washings were added to the original solution. The solutions were filtered and the amount of undissolved material determined. The liquids were made up to definite volumes and aliquot portions taken for analysis. (See Table pp. 9.)

The results show that on the whole the incrustations are very similar, consisting principally of calcium carbonate. It is interesting to note here that the waters at the several plants furnishing the samples are of the same general character, containing considerable quantities of Magnesium and Calcium carbonate and Magnesium sulphate.

Analyses of Incrustations of the Sands.

Name of Sand.	Determination Made -- Per cent. Quincy	Moline	Kankakee	Danville No. 8	Danville No. 6.
Insoluble Matter.	0.32	1.20	1.83	7.58	5.89
Oxides of Iron and Alumina (Fe_2O_3 Al_2O_3)	0.42	0.94	7.20	3.15	2.20
Magnesium Oxide (MgO)	0.83	0.12	1.09	1.00	1.16
Calcium Oxide (CaO)	54.03	53.10	47.75	47.70	49.58
Sulphur Trioxide (SO_3)	0.14	0.12	0.31	0.17	0.17

Name of Sand	Hypothetical Combinations - Per cent. Quincy	Moline	Kankakee	Danville No. 8.	Danville No. 6.
Insoluble Matter	0.32	1.20	1.83	7.58	5.89
Magnesium Sulphate	0.21	0.18	0.48	0.25	0.26
Magnesium Carbonate	1.63	1.37	2.00	1.90	2.23
Calcium Carbonate	96.48	94.83	85.26	85.17	88.53
Ferrous Carbonate.	0.61	1.37	10.44	4.57	3.19

The large quantity of insoluble matter in the case of the Danville filter is doubtless due to the fact that at times the river, from which the supply is drawn, becomes very turbid and thus carries large amounts of sediment on to the filter beds.

The high percentage of ferrous carbonate, which includes the aluminum contents, in the case of the Kankakee sand, is interesting and difficult to account for. No alum was used at this plant for a year previous to the time the sample was taken, so the

presence of Aluminium hydroxide due to a recent addition of alum is impossible.

The water at Moline and Quincy have received parallel treatment with lime and iron sulphate.

It is also interesting to examine the percentage of incrustation with reference to the amounts of coagulants used at the several plants. We find Quincy heading the list with 2.84 grains of lime, 2.05 grains of iron sulphate, and an incrustation of 85%. Moline comes next with 3.00 grains of lime and 1.00 grains iron sulphate, and an incrustation of 71.4%. Danville ranks third with amounts of lime varing from .27 to 2.50 grains of iron sulphate from .58 to 4.00 grains. The incrustation is 32.3 per cent Kankakee comes last with an incrustation of 13.7%. This is doubtless due to the fact that lime and iron sulphate have been used at this plant for a very short time as compared with the other plants.

A year or so ago an incrustation four inches in thickness was removed from one of the pipes at the Quincy water works. The composition of the incrustation was as follows:- (Table pp 11)

Bulletin University of Illinois, W. S. Series No. 7 pp. 28, and 35.

Analysis of The Incrustation at Quincy.

Determination made.		Percent.
Moisture		.13
Loss on ignition less Moisture		44.31
Silicious Matter		.30
Silica SiO_2.	.15%	
Oxides of Iron and Alumina Fe_2O_3 Al_2O_3		.86
CaCeium Oxide CaO		53.54
Calcium Ca.	38.27%	
Magnesium Oxide MgO		.13
Magnesium Mg.	.08	
Sulphur trioxide SO_3		.33
Sulphate SO_4	.39	
Sodium Oxide Na_2O		.16
Sodium Na.	.12	
		99.76

Hypothetical Combinations.

	Percent.
Sodium Sulphate Na_2SO_4	.37
Magnesium Sulphate Mg SO_4	.17
Magnesium Carbonate $MgCO_3$	.17
Calcium Carbonate $CaCo_3$	95.53
Oxides of Iron and Alumina Fe_2O_3 Al_2O_3	.86
Silicious Matter	.30
Moisture	.13
Loss on Ignition less water plus CO_2 Organic matter	2.23
	99.76

At that plant lime and iron sulphate were added to the water The iron sulphate solution was drawn by the suction of the pump forcing the water from the intake well to the settling basin. The lime was pumped into the discharge pipe by a small pump. The discharge from the lime pump was connected with the discharge from the large pump in a valve well just outside the pump house. This allowed a thorough mixing of the solutions with the raw water before they reached the sedimentation basin. The water was then carried from the sedimentation basin to the filter by a 20" pipe. It was in the pipe leading from the intake well to the basin and beyond the point where the coagulants were added, that the incrustation occurred. It would seem therefore that the composition of this incrustation and that on the Quincy sand, should be very similar. A glance at the analysis shows this to be true.

Incrustation, Experience at Quincy, Illinois. W. R. Gelston Proc. Am. Water Works. Assn. 1908, 165.

Character and Composition of the Incrustation from Discharge Pipe at Quincy, Illinois. Edward Bartow, Proc. Am. Water Works Assc. 1908, 172.

Also University of Ill. Bulletin --W. S. Series No. 7 Page 28, 35.

The foregoing has shown us the extent and character of the incrustation. In what follows we have tried to study the problems of the prevention of an incrustation due to the action of

lime used in the treatment of water.

The chief constituent of the incrustation is, as we have shown above, calcium carbonate. This is formed in the raw water by the action of the lime on the calcium bicarbonate, according to the equation -- $Ca(OH)_2 + Ca(HCO_3)_2 = 2CaCO_3 + 2H_2O$.

This reaction is not instantaneous but requires considerable time to run to completion. Consequently if the water is carried to the filter beds too soon, calcium carbonate is precipitated and incrustation results.

It is, therefore, the addition of lime and subsequent formation of calcium carbonate that brings about the condition necessary for the precipitation on the filter beds. The presence of the hydroxide ion of the lime can be shown by titrating a portion of the water with standard acid, using phenolpthalein for an indicator. A titration of this kind with phenolpthalein will show all the hydroxide, or caustic alkalinity, and one half of the normal carbonate alkalinity. If, then we can remove this caustic alkalinity we can prevent the subsequent formation of calcium carbonate and hence incrustation.

In some cases this has been accomplished by burning lime stone in a kiln and passing the carbon dioxide generated through the water before it passes on the filters, thus changing the calcium carbonate to the very soluble bicarbonate.

The Municipal Journal and Engineer, September 4 - 1907.

It was noticed while looking up the literature on the various filter and purification plants that where alum or iron sulphate was used without lime or where small amounts of either alum or iron sulphate were added sometime after the addition of lime that no complaint of incrustation occurred. The plant at Columbus, Ohio, affers a good example of this mode of treatment. Here ferrous sulphate is added to the raw water and a little later lime. After a period of sedimentation a second addition of a very small amount of ferrous sulphate is made just before the water passes on the filters. The reason given for this second addition of coagulant is, that it causes a slight flock which settles on the filters and greatly increases the bacterial efficiency. A study of the data from the plant shows, however, that the alkalinity is markedly reduced.

Municipal Journal and Engineer, May 11 - 1910.

A somewhat similar proceedure is followed at the New Orleans plant with practically the same results.

Municipal Journal and Engineer May 6, 1908.

Engineering Record. April 23, 1910.

It would seem possible then to remove, or at least materially decrease the caustic alkalinity, by the addition of small amounts of aluminium sulphate or ferrous sulphate just before the water passes on the filters. The reaction probably proceeds ac-

cording to the following equations.

$$3CaCo_3 + Al_2(SO_4)_3 = 3CaSO_4 + Al_2(CO_3)_3$$

$$Al_2(CO_3)_2 + 6H_2O = 2Al(OH)_3 + 3CO_2$$

$$CaCO_3 + CO_2 + H_2O = CaH(CO_3)_2$$

$$3H_2O + 3CaSO_4 + Al_2(SO_4)_3 = 2Al(OH)_3 + 3CaSO_4 + 3CO_2$$

$$3CO_2 + 3CaCO_3 + 3H_2O = 3Ca(HCO_3)_2$$

$$3Ca(OH)_2 + AL_2(SO_4)_3 = 3CaSO_4 + 2Al(OH)_3$$

The soluble calcium sulphate remains in the water while the aluminium or ferric hydrate, as the case may be, is caught on the filters. This material being very light, is easily removed by washing.

This proceedure was tested by adding definite amounts of alum and iron sulphate to water which had been previously softened by lime, filtering off a portion at definite intervals and titrating it with standard acid. The aluminium and ferrous sulphate were added in the form of solutions with a strength of 1%. The $Al_2(SO_4)_3$ and $FeSO_4$ content of these solutions was determined by gravimetric analysis.

The amount of coagulant is expressed in parts per Million and grains per U. S. gallon of anhydrous ferrous and aluminum sulphate.

University of Illinois Water.

Amount of Alum. Grains per gallon.	Pts. per M.	Time between addition of Alum & titration	Phenolphthalein Alkalinity.	Methyl Orange Alkalinity.	Reduction in Phenolphthalein Alkalinity	Reduction in Methyl Orange Alkalinity
-----	Raw	Water	66.0	137.0	-- --	----
0.88	15.0	00 Min.	53.0	128.0	13.0	9.0
"	"	5 "	52.0	128.0	14.0	9.0
"	"	15 "	50.0	127.0	16.0	10.0
"	"	40 "	50.0	128.0	16.0	9.0
"	"	60 "	49.0	128.0	17.0	9.0
"	"	120 "	50.0	127.0	16.0	10.0
1.77	30	00 Min.	40.0	118.0	26.0	19.0
"	"	5 "	39.0	117.0	27.0	20.0
"	"	15 "	39.0	117.0	27.0	20.0
"	"	40 "	40.0	117.0	26.0	20.0
"	"	60 "	40.0	117.0	26.0	20.0
"	"	120 "	39.0	117.0	27.0	20.0
2.36	40	00.0	26.0	112.0	40.0	25.0
"	"	5 Min.	27.0	112.0	39.0	25.0
"	"	15 "	26.0	113.0	40.0	24.0
"	"	40 "	26.0	112.0	40.0	25.0
"	"	60 "	25.0	111.0	41.0	26.0
"	"	120 "	24.0	111.0	42.0	26.0

University of Illinois Water.

Amount of Iron grains per gal.	Amount of iron sulphate pts. per M.	Time between addition of Iron sulphate and titration	Phenolphthalein Alkalinity.	Methyl Orange Alkalinity.	Reduction in Phenolphthalein Alkalinity.	Reduction in Methyl Orange Alkalinity.
- - -	Raw	Water	64.0	132.0	- - -	- - -
0.9	15	00 Minn	50.0	120.0	14.0	12.0
"	"	5 "	49.0	120.0	15.0	12.0
"	"	15 "	49.0	121.0	15.0	11.0
"	"	40 "	50	121.0	14.0	11.0
"	"	60 "	49.0	120.0	15.0	12.0
"	"	120. "	49.0	120.0	15.0	12.0
1.77	30	00 Minn	41.0	111.0	23.0	21.0
"	"	5 "	40.0	111.0	24.0	21.0
"	"	15. "	40.0	112.0	24.0	20.0
"	"	40 "	41.0	111.0	23.0	21.0
"	"	60 "	40.0	111.0	24.0	21.0
"	"	120 "	40.0	111.0	24.0	21.0
2.36	40	00 Minn	31.0	105.0	33.0	27.0
"	"	5 "	31.0	104.0	33.0	28.0
"	"	15 "	32.0	105.0	32.0	27.0
"	"	40 "	31.0	105.0	33.0	27.0
"	"	60 "	31.0	104.0	33.0	28.0
"	"	120 "	30.0	104.0	34.0	28.0

These results show that the phenolpthalein alkalinity can be much reduced either by alum or ferrous sulphate, and that this reaction is about instantaneous.

The water used in these tests contained Na_2CO_3 to the extent of 76.0 parts per million. This of course would give a high phenolpthalein alkalinity, which would form no incrustation upon the sand, and hence need not be removed. If this alkalinity be subtracted **from** the total phenolpthalein alkalinity of the water, we find that the remainder, or the alkalinity due to the OH and $1/2CO_3$ ions is reduced to 14.0 parts per million when 15 parts per million of alum were used. When 30 parts per million of alum were used only 4.0 parts per million of this alkalinity remained and when 40 parts of alum were added 13.0 parts of the phenolpthalein alkalinity due to Na_2CO_3 were removed.

The addition of iron sulphate gave corresponding results, except that the reduction was less.

In order to get nearer to working conditions waters of the character generally treated in filter plants in this state were tested. Not enough lime was added to give an excess of caustic alkalinity, but just enough to raise the phenolpthalein alkalinity to about 20 parts per million. It might be mentioned here that the phenolpthalein alkalinity is the alkalinity due to hydrates and to one-half the carbonates. When the alkalinity to both Methyl Orange and phenolpthalein is found this caustic alkalinity, or alkalinity due to hydrates is obtained by subtracting

the methyl orange alkalinity from twice the phenolpthalein. The alkalinity due to carbonates is obtained by subtracting the phenolpthalein alkalinity from the Methly orange alkalinity and multiplying the result by two.

(See tables, Pages 20, 21, and 22).

From these results it is plain that Aluminium sulphate and iron sulphate have a very marked effect upon the phenolpthalein alkalinity of water treated with lime. This reaction is apparently instantaneous as the reduction in alkalinity after two hours is practically the same as that upon the mixing of the solutions.

The Methyl orange alkalinity is also affected to a large extent but not so much as the phenolpthalein alkalinity. The reduction also does not seem to increase in the same proportion as the reduction of phenolpthalein alkalinity with an increase in the amount of alum or iron used.

The reduction, when the same number of parts per million of iron and alum are added, is greater in the case of the alum. This is to be expected, however, from the chemical formulae of the two compounds. Alum, as it is obtained on the market, generally contains only about 17% aluminium oxide or 57% $Al_2(SO_4)_3$. This means that chemically the material is only about 3/5 as efficient as if it were ~~pure~~ anhydrous. Ferrous sulphate, as obtained on the market, contained about 55% $FeSO_4$. ~~Therefore~~ It requires two molecules of ferrous sulphate to equal one molecule of alum. Chemically,

Kankakee Water.

Amount of Alum grains per gal.	Amount of Alum used Pts. per M.	Time between addition of Alum and titration	Phenolphthalein Alkalinity.	Methyl Orange Alkakinity.	Reduction in Phenolphthalein Alkalinity.	Reduction in Methyl Orange. Alkalinity
Raw	Water	- - -	18.0	34.	- - -	- - -
0.59	10.0	0	9.0	29.0	9.0	5.0
"	"	5 Min.	9.0	28.0	9.0	6.0
"	"	15 "	9.0	29.0	9.0	5.0
"	"	40 "	9.0	29.0	9.0	5.0
"	"	60 "	8.0	28.0	10.0	6.0
"	"	120 "	8.0	29.0	10.0	5.0
0.90	15.0	0 Min	3.0	28.0	15.0	6.0
"	"	5 "	3.0	29.0	15.0	5.0
"	"	15 "	3.0	29.0	15.0	5.0
"	"	40 "	4.0	27.0	14.0	7.0
"	"	60 "	3.0	28.0	15.0	6.0
"	"	120 "	3.0	28.0	15.0	6.0
1.18	20.0	0 min	0.0	25.0	- - -	9.0
"	"	5 "	0.0	26.0	- - -	8.0
"	"	15 "	0.0	26.0	- - -	8.0
"	"	40 "	0.0	25.0	- - -	9.0
"	"	60 "	0.0	26.0	- - -	8.0
"	"	12 0 "	0.0	25.0	- - -	9.0

Kankakee Water.

Amount of Iron sulphate grains per gal.	Amount of iron sulphate parts per M.	Time between addition of iron and titration	Phenol-pthalein Alkalinity.	Methyl Orange Alkalinity.	Reduction in Phenol-phthalein Alkalinity	Reduction in Methyl Orange Alkalinity
Raw water			18.0	34.0	- - -	- - -
0.59	10.0	00	6.0	25.0	12.0	9.0
0.59	10.0	5 min.	7.0	25.0	11.0	9.0
0.59	10 0	15 "	7.0	24.0	11.0	10.0
0.59	10.0	40 "	7.0	25.0	11.0	9.0
0.59	10.0	1 hr.	6.0	24.0	12.0	10.0
0.59	10.0	2 "	6.0	24.0	12.0	10.0
Raw water			19.0	39.0	- - -	- - -
0.56	9.5	00	9.0	31.0	10.0	8.0
0.56	9.5	5 min.	9.0	31.0	10.0	8.0
0.56	9.5	15 "	10.0	31.0	9.0	8.0
0.56	9.5	40 "	9.0	30.0	10.0	9.0
0.56	9.5	1 hr.	9.0	30.0	10.0	9.0
0.56	9.5	2 "	8.0	30.0	11.0	9.0
Raw water			14.0	33.0	- - -	- - -
1.18	20.0	00	0.0	17.0	- - -	16.0
1.18	20.0	5 min.	0.0	18.0	- - -	15.0
1.18	20.0	15 "	0.0	17.0	- - -	16.0
1.18	20.0	40 "	0.0	17.0	- - -	16.0
1.18	20.0	1 hr.	0.0	18.0	- - -	15.0
1.18	20.0	2 "	0.0	17.0	- - -	16.0

Danville Water.

Amount of Alum in grains per gal.	Amount of Alum in parts per M.	Time between addition of Coagulant and titration	Phenol-pthalein Alkalinity.	Methyl Orange Alkalinity.	Reduction in Phenol-pthalein Alkalinity	Reduction in Methyl Orange Alkalinity.
Raw water			23.0	122.0	- - -	- - -
0.44	7.5	00	16.0	118.0	7.0	4.0
0.44	7.5	5 min.	17.0	118.0	6.0	4.0
0.44	7.5	15 "	17.0	118.0	6.0	4.0
0.44	7.5	40 "	17.0	118.0	6.0	4.0
0.44	7.5	1 hr.	17.0	118.0	6.0	4.0
0.44	7.5	2 "	16.0	118.0	7.0	4.0
Raw water		- - -	21.0	135.0	- - -	- - -
0.90	15.0	00	8.0	126.0	13.0	9.0
0.90	15.0	5 min.	7.0	127.0	14.0	8.0
0.90	15.0	15 "	7.0	127.0	14.0	8.0
0.90	15.0	40 "	6.5	127.0	15.0	8.0
0.90	15.0	1 hr.	6.0	126.0	15.0	9.0
0.90	15.0	2 "	6.0	126.0	15.0	9.0
Danville Water plus $FeSO_4$						
Raw water			17.0	135.0	- - -	- - -
0.44	7.5	00	8.0	128.0	9.0	7.0
0.44	7.5	5 min.	8.0	128.0	9.0	7.0
0.44	7.5	15 "	8.0	127.5	9.0	8.0
0.44	7.5	40 "	7.0	128.0	10.0	7.0
0.44	7.5	1 hr.	- -	- - -	- - -	- - -
0.44	7.5	2 "	8.0	129.0	9.0	6.0

~~however~~ through, it requires ~~three~~ Two molecules of iron sulphate to equal one of alum, ~~therefore~~ the iron sulphate is ~~only 2/3~~ 1/2 as efficient as alum, pound for pound. When we consider, however, that iron sulphate can be procured for 45 to 55¢ per 100 lbs. while alum costs $1.00 per 100 lbs.we see that treatment with iron sulphate is by far the cheaper.

After treatment with iron sulphate, the water seemed to have a faint yellowish tint even after filtration. This suggests the idea that probably there are some waters which cannot be treated satisfactorily with ferrous sulphate, and further study along this line would be interesting. The color might be due to a small portion of the iron passing through the filters in an undissociated form and hydrolizing later, or to imperfect filtration due to insufficient coagulation of the precipitate, or to lack of dissolved oxygen. It is maintained, however, if the water has sufficient alkalinity and is thoroughly agitated for three minutes after the addition of the iron sulphate that the precipitate will settle in large flakes and the effluent be perfectly clear and colorless.

The Engineering Record. October 9, 1909.

The above data indicates that by addition of small amounts of alum or iron sulphate just before the water goes on the filter the alkalinity due to CO_3 and OH ions can be much reduced. And since it is this caustic alkalinity that causes incrustation the tendency to form incrustation can be reduced.

There is another point to be considered in this connection.

If the reaction of the alum ($Al_2(SO_4)_3$ plus $3CaCO_3$ plus $3H_2O$ equals $2Al(OH)_3$ plus $3CaSO_4$ plus $3CO_2$) is not complete in a very short time portions of it will pass through the filters (as $Al_2(SO_4)_3$) without dissociation. This part may undergo decomposition at a later period ($Al_2(SO_4)_3$ plus $6H_2O$ equals $2Al(OH)_3$ plus $3H_2SO_4$) and cause a deposit in the distribution system.

It has been stated that if the water is stirred for three minutes after the addition of the coagulant the flock will settle out in large flakes, and filtration through a single thickness of filter paper will give a bright, clear effluent.

The Engineering Record, October 9, 1909.

However small portions of the iron might pass the filters undissociated, thus not being perceptible in the filtrate and yet offering the possibility of later precipitation.

An attempt was made, in the following manner, to discover if such an after reaction occurred. after addition of the coagulant samples were filtered off at definite periods and set aside for several days. When examined there seemed to be a slight flock in the bottom of the flasks, but it was not sufficiently marked to distinguish any difference in the samples drawn off at different periods. These samples were titrated with standard acid as before. In this case only the methyl orange alkalinity was considered for the phenolpthalein alkalinity might be much affected by the absorbtion of carbondioxide and hence would be no index of any further reaction with the coagulant.

The results are shown in the following tables:-

Danville Water.

Amount of Alum added Grains per gallon	Amount of Alum added Parts per M.	Time between addition of Alum and Titration.	Phenolpthalein Alkalinity.	Methyl Orange Alkalinity.	Methyl Orange Alkalinity, after 48 hrs.	Reduction in pth. Alkalinity.	Reduction in Methyl Orange Alkalinity.	Reduction in Methyl Orange Alk. after 48 hrs.
Raw Water			23.0	122.0	- -	- -	- -	- - -
0.45	7.5	00	16.0	118.0	115.0	7.0	4.0	7.0
"	7.5	5min.	17.0	118.0	116.0	6.0	4.0	6.0
"	7.5	15 "	17.0	118.0	116.0	6.0	4.0	6.0
"	7.5	40 "	17.0	118.0	115.0	6.0	4.0	7.0
"	7.5	1 hr.	17.0	118.0	116.0	6.0	4.0	6.0
"	7.5	2 "	15.5	117.5	116.0	6.0	4.5	6.0
"	7.5	3 "	16.0	118.0	116.0	7.5	4.0	6.0
"	7.5	4 "	15.0	117.0	115.0	7.0	5.0	7.0
"	7.5	5 "	13.0	117.0	116.0	18.0	5.0	6.0
"	7.5	6 "	12.5	116.5	116.0	10.0	5.5	6.0
"	7.5	24 "	7.5	116.0	115.0	10.5	6.0	7.0
Raw Water			21.0	135.0	- -	- - -	- - -	- - -
0.90	15.	00	7.5	126.0	125.0	13.5	9.0	10.0
"	"	5 min	7.0	127.0	126.0	14.0	8.0	9.0
"	"	15 "	7.0	127.0	125.0	14.0	8.0	10.0
"	"	40 "	6.5	127.0	124.0	14.5	8.0	11.0
"	"	1 hr.	6.0	126.0	124.0	15.0	9.0	11.0
""	"	2 "	5.0	126.0	125.0	16.0	9.0	10.0
"	"	3 "	- -	- -	- - -	- -	- -	- -
"	"	4 "	5.5	126.0	125.0	15.5	9.0	10.0
"	"	5 "	5.0	125.5	125.0	16.0	9.5	10.0
"	"	6 "	4.5	125.0	124.0	16.5	10.0	11.0
"	"	24 "	4.0	125.0	125.0	17.0	10.0	10.0

Danville Water.

Amt. of Iron added Grains per gal.	Amt. of Iron added parts per M	Time between addition of Alum & Titra.	Pth. Alkalinity	Methyl Orange Alkalinity.	Methyl Orange Alk. after 48 hrs.	Reduction in Pth. Alk.	Reduction in Methyl Orange Alk.	Reduction in Mvl. O Alk. Af 48 hrs.
Blank Sample			17.0	135.0	- - -	- - -	- - -	- -
0.68	11.5	00	6.0	128.0	125.0	11.0	7.0	10.0
"	11.5	5 min	8.0	128.0	125.0	9.0	7.0	10.0

(continued)

Danville Water

0.68	11.5	15 min	8.0	127.5	126.0	9.0	7.5	9.0
"	"	40 "	7.0	128.0	125.0	10.0	7.0	10.0
"	"	1 hr.	- -	- -	- - -	- -	- -	
"	"	2 "	8.0	129.0	124.0	9.0	6.0	11.0
"	"	3 "	7.0	127.0	125.0	10.0	8.0	10.0
"	"	4 "	7.0	127.0	127.	10.0	8.0	8.0
"	"	5 "	6.0	126.0	125.0	11.0	9.0	10.0
"	"	6 "	6.0	126.0	125.0	11.0	9.0	10.0
"	"	24 "	5.0	125.0	126.0	12.0	10.0	9.0

Belleville Water.

Amt. of Alum added.		Time between addition of Alum & Titra.	Pth. Alkalinity.	Methyl Orange Alkalinity.	Methyl Orange Alkalinity after 48 hrs.	Reduction in Pth. Alkalinity.	Reduction in Methyl Orange Alk.	Reduction in M.O. Alka. after 48 hrs.
Grains per gallon	Parts per M.							
0.45	7.5	- -	39.0	130.0	- -	- -	- - -	- - -
0.45	7.5	00	30.0	128.0	123.0	9.0	2.0	7.0
"	"	5 min	30.0	127.0	- - -	9.0	3.0	- -
"	"	15 "	29.0	128.0	- - -	10.0	2.0	- -
"	"	40	30.0	128.0	124.0	9.0	2.0	6.0
"	"	1 hr.	31.0	128.0	123.0	8.0	2.0	7.0
"	"	2 "	30.0	127.0	124.0	9.0	3.0	6.0
"	"	3 "	30.0	127.0	124.0	9.0	3.0	6.0
"	"	4 "	30.0	127.0	123.0	9.0	3.0	7.0
"	"	5	28.0	126.0	124.0	11.0	4.0	6.0
"	"	6 "	26.0	127.0	124.0	13.0	3.0	6.0
"	"	7 "	25.0	127.0	124.0	14.0	3.0	6.0
"	"	24 "	11.0	124.0	124.0	28.0	6.0	6.0
0.9	15.0	- -	38.0	130.0	- -	- -	- -	- - -
"	"	00	25.0	126.0	120.0	13.0	4.0	10.0
"	"	5 min.	25.0	125.0	119.0	13.0	5.0	11.0
"	"	15 "	25.0	125.0	- - -	13.0	5.0	- -
"	"	40 "	24.0	125.0	- -	14.0	5.0	- -
"	"	1 hr.	25.0	125.0	120.0	13.0	5.0	10.0
"	"	2 "	22.0	125.0	120.0	16.0	5.0	10.0
"	"	3 "	24.0	124.0	121.0	14.0	6.0	9.0
"	"	4 "	23.0	124.0	120.0	15.0	6.0	10.0
"	"	5 "	21.0	123.0	120.0	17.0	7.0	10.0
"	"	6 "	21.0	124.0	118.0	17.0	6.0	12.0
"	"	24 "	9.0	119.0	120.0	19.0	11.0	10.0

It appears from these results that while the reaction betwee the alum and the calcium carbonate is apparently complete in a very short time, there is in reality a small amount of alum unaffected. This portion seems to have completely dissociated at the end of twenty-four hours, as the alkalinity after forty-eig hours is the same as at the end of the twenty-four hour period. This after reaction is very slight as compared with the total reaction of the alum with the phenolpthalein alkalinity, and the precipitation that results from it is so small as to be almost negligible.

In conclusion it may be stated that at plants where the water is partially softened with lime, growth, by incrustation, of the filter sands will result, unless some means are used to prevent it. This growth consists largely of calcium carbonate togetherwith small amounts of the other mineral salts present in the water. It not only causes the loss of large amounts of sand, but so increases the size of the grains as to decrease greatly the efficiency of the filters.

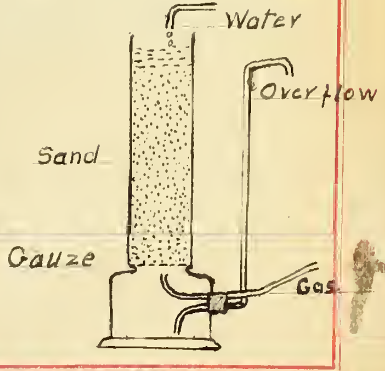
According to the data shown above, this incrustation can be prevented, or at least much decreased by the addition of a small amount of aluminium or ferrous sulphate before the water passes on to the filters. It may be further assumed that the coagulant so added will have a tendency to remove the incrustation already formed, as the experience of Mr. Cobb at the Kankakee plant indicates.

It cannot be denied that there is a small portion of the

coagulant which does not enter into the reaction at first, but which reacts more slowly, making a slight flock after standing some time. This secondary reaction or precipitation is very slight, however, and would seem scarcely sufficient to cause trouble by incrustation of the pipes beyond the filters. This reaction is complete in 24 hours and if the coagulant be added sometime before filtration, there is no danger that the delayed precipitation will cause trouble, as shown by the experience of the New Orleans and Columbus plants where this practice is followed.

It is the custom at most filtering plants to stir the sand in the bed, usually with compressed air, once in every twenty-four hours, or oftener at the time of washing. Therefore it occurred to us that this might be done with some gas that would have a solvent affect upon the incrustation instead of with air as is the general practice.

A portion of incrusted sand which was dried and weighed was placed above a wire gauze in a glass cylinder. Below the gauze was a chamber with an opening into which a stopper was fitted carrying a tube for the delivery of gas directly under the gauze and (2) an outlet tube for the water which had passed through the sand into the chamber below. This tube was bent upwards and reached slightly above the level of the sand. Carbon dioxide was forced under constant pressure through the tube into the chamber from which it passed upward through the



gauze and sand. At the same time distilled water was allowed to flow onto the surface of the sand and thence to find its way downward to the chamber below. From here it rose in the outlet tube and gradually overflowed into a basin. Great difficulty was experienced in keeping the gas pressure such that the water would overflow continuously and slowly from the pipe. Occasionally the gas would force all the water from the chamber below the gauze and from the overflow pipe, and hence considerable gas was lost. On this account the volume of gas used is far in excess of what is necessary to accomplish the work, after several hours of this treatment the sand was removed, dried and weighed. This process was repeated several times with the same sample of sand. The results appear below.

Amount of Water used.	Amount of CO_2 Used.	Original Wt. of sand.	Final Wt. of sand.	Amount of loss.
4000 c,c,	20,000 c.c.	681.5 gr.	675.0 gr.	6.5 gr.
2000 c.c.	2,500 c.c.	675.5 gr.	672.5 gr.	2.5
2000 c.c.	2,000 c.c.	672.5 gr.	669.0 gr.	3.5 gr.

The large amount of gas consumed in the first test may be accounted for by considering the solubility of the CO_2 in the water used to drive it from the gasometer. The same water was was used in both the other tests, but as it was nearly saturated it absorbed little gas.

It might be mentioned that the water caught in the basin under the overflow pipe was slightly turbid and left a deposit on standing.

To be certain the loss in weight was not simply a loss due to the solvent action of the water or to the removal of some loose dirt clinging to the surface of the sand, the treatment was repeated using air in place of the CO_2. This caused no appreciable difference in the weight of the sample.

The same sample was then again subjected to the treatment with carbon dioxide and water with the same results as before. This would seem to prove beyond a doubt that the decrease in weight was due to the action of the CO_2 on the incrustation. The action being the transformation of the calcium carbonate, which composed the greated part of the incrustation, into the very soluble bicarbonate.

Considering that it would be impracticable to use pure CO_2 on a commercial scale, an attempt was made to substitute flue gases. This gas was obtained from the furnaces of the University boilers.

Amount of Water used.	Amount of Gas used.	Original Wt. of Sand.	Final Wt. of Sand.	Amount of loss.
2,000 c.c.	20,000 c.c.	669 gr.	668 gr.	1.0 gr.
2,000 c.c.	20,000 c.c.	668 gr.	667 gr.	1.0 gr.

The same sample of sand that was used in the previous experiments was subjected to treatment with this gas and distilled water. At every treatment the sand was decreased in weight but the decrease was not so marked as when pure carbon dioxide was used.

These tests indicate that if the sand in the filters was

stirred with flue gas instead of air the tendency would be to remove any incrustation. While the action is slight compared to the amount of gas used, yet when consideration is taken of the fact that the incrustation forms very slowly, indeed, it seems probable that the use of flue gas every twenty-four hours would dissolve the incrustation as fast as it formed, and hence prevent the growth of the sand.

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